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EFFECT OF WINDS AND OTHER WEATHER CONDITIONS ON THE FLIGHT OF AIRPLANES.

By CHARLES F. BROOKS and OTHERS.

[Dated: Weather Bureau, Washington, Oct. 3, 1919.]

SYNOPSIS.—By means of data collected from numerous sources relative to meteorological phenomena observed in flying, an attempt is made in this paper to explain on a scientific basis, for the benefit of the aviator, the phenomena he has observed, and at the same time to gather from these experiences such facts as are of value to the meteorologist in amplifying his knowledge of what actually exists in the upper air.

The disturbances of the air due to daytime convection are one of the prime sources of bumpiness. Especially on hot summer days do strong, rapidly rising currents of air penetrate to great altitudes and, where encountered, jolt the aeroplane. Where the cooler air is descending, the effect is similar to that of falling into a "hole." The height to which the effects of surface roughness extend when the wind is blowing depends upon the speed of the surface wind and the height of the obstruction.

In the free air, aviators' observations show how the layers of air flow over one another, the interface sometimes being marked by clouds and sometimes entirely invisible. At such levels are encountered billows or waves, and considerable difficulty is sometimes experienced in flying through such regions. Clouds, rain, and fog all contribute to the discomfort and danger of flying.

Perhaps the most interesting are the experiences in the thunderstorms and the up-and-down winds which accompany such storms. As the driving wedge of cold air at the surface advances ahead of the storm, the air into which the storm is moving is forced upward. The maximum turbulence is found in the region of the squall cloud, but the force of the rising air ahead of the storm is sufficient to carry up airplanes considerably, in spite of the efforts of the pilots to keep the nose of the plane down. The dangers from lightning and hail, are also quite as important as those from the capricious winds.

INTRODUCTION.

In a mutual discussion of the meteorological aspects of aviation the aviator and the meteorologist obtain much valuable information. The aviator tells the meteorologist his experiences with various air conditions, and the meteorologist attempts to explain how such conditions are produced, how best to avoid the unfavorable ones, and how to take advantage of the favorable. Furthermore, the information which the aviator can give the meteorologist helps to explain many doubtful weather phenomena which the meteorologist has not been able to observe personally at close range. To obtain facts essential for this paper, about 50 experienced aviators have been consulted. In several cases Signal Corps meteorologists themselves have made flights or have prevailed on others to investigate carefully certain points about which further information was needed. In addition, we have used freely the numerous reports, "Meteorological aspects of aviation" written by Dr. Griffith Taylor's student aviators and published in the Australian Monthly Weather Report (1); and also have gathered numerous accounts of aviators' experiences published in aeronautical journals and elsewhere.

We have attempted to classify these experiences under the headings: (1) surface winds—effects of local heating, and effects of surface configuration; (2) winds of the free air, turbulent wind boundaries, and flying in clouds and rain; (3) thunderstorms. With each group we have offered explanations. The explanations are, in a large part, presented here without any claim to originality; most are embodied in numerous papers which have already been published here and abroad.[1] In quoting the assertions of aviators the authors do not necessarily subscribe to the entire correctness of the inferences carried or implied.

SURFACE WINDS—LOCAL CONVECTIONAL CURRENTS.

Experiences of aviators.—A most common experience of aviators is daytime bumpiness. The bumps in the air may be described in terms of those felt while riding in different kinds of automobiles on roads of varying roughness.

The aviator may be experiencing moderate bumps and suddenly encounter one sharp enough to "throw the fire extinguisher into my lap" or to "set the ship nearly up on end." Then there may be a little more smooth flying until suddenly the support seems to disappear, the propeller appears to give no headway, and down goes the airplane. A bump may announce the bottom, and the aviator slowly climbs again to his proper level. As seen from the ground on a "bumpy" day, the airplane tilts from side to side to a maximum of 30° from the horizontal, and now and then some sharp up or down motion is discernible. The tilts may give the ship a side slip, which will sometimes be sufficient to remove it from one side of a V formation to the other. When such a side slip occurs too near the ground, one of the airplane accidents characteristic of a hot day in the South occurs.

In general, there appear to be differences of opinion among pilots as to the intensity or magnitude of the vertical movement on bumpy days; this is probably due to the different localities in which the flying was done, or to the pilots' experience. (Experienced pilots are usually the most conservative.) It has been suggested that observers are much more sensitive to these atmospheric phenomena than the pilots, since they have not the management of the plane to occupy their attention. All say that for ordinary bumps a change of 50 feet is common. A change of 200 feet is experienced at times, and occasionally an aviator comes in with a story of having risen or fallen 500 feet. Others have reported sudden drops of still greater magnitude, but it is possible that only the initial fall was due to the bump and the consequent loss of altitude was due to the aviator's inability to right the airplane immediately. The larger and faster the airplane the less is the change of altitude due to bumps. Most of the aviators say that unless flying in formation, it is impossible to tell the amount of up or down motion with a bump or in a "hole" without watching the altimeter. Flying in a squadron formation on a bumpy day in Texas is described as an interesting

[1] See Bibliography on p. 532.

FIG. 1.—Late afternoon, double layer of clouds: broken alto-stratus and stratus.

FIG. 2.—Thick layer of strato-cumulus; cirro-stratus above.

sight, but a difficult performance. The different ships are going up or down and getting out of formation continually. An aviator who was flying second on one leg of a V said that the leader, who was about 100 feet in front and a little off to the side, went up suddenly about 300 feet, but that *his* ship kept on the same level and felt no disturbance. On another occasion the air being very bumpy, the first airplane in a V formation suddenly rose 300 feet, and a few seconds later the second did the same. Evidently the edges of the conditions which caused bumps are at times very sharp.

Most bumps in the air occur near the ground and on bright, hot days. In the northeastern United States, 3,000 to 5,000 feet is the upper limit of bumpiness on a summer day, though in very hot weather, bumpiness, sometimes extreme, occurs at elevations even above 8,000 feet. In Texas the air is bumpy sometimes to more than 10,000 feet. In winter the usual limit of bumpiness at Ellington Field, Tex., is 1,500 to 2,000 feet. Ordinarily, however, the extremely bumpy conditions are within 500 to 2,500 feet of the ground or just under and about cumulus clouds. For example:

A cloud of the cumulo-nimbus type is often met with, and, as a rule, to avoid it the engine is throttled down, and a dive is made some 20 to 50 feet below it. As the machine assumes its normal flight path again, while under the cloud, it is subjected to very strong gusts, sometimes spasmodic in duration and at all times variable in direction. Again, under the same cloud another movement of an oscillatory character is encountered. The oscillations, as a rule, are very slow, for they produce in the aeroplane considerable undulation about the pitching axis; thus, for a few seconds the machine is subject to a strong lift, then the nose is forced down, sometimes causing a steep dive. Still yet another distinct and even more interesting disturbance is met here, in the shape of a rapid vibratory effect on the machine. This is probably due to a horizontal head or following wind whose speed rapidly alternates between a low minimum and a high maximum—*Lieut. F. H. McNamara, Australian Monthly Weather Report August 1913, page 431.*

In the interior of Texas flying is generally not attempted in the hottest hours of bright summer days because the air is dangerously bumpy. Here is a case of a crash ascribed to "heat bumps":

Lieut. F. W. Keller and Sergt. E. Chapman on leaving Clarksdale, Miss., June 17, 1918, "had difficulty in attaining altitude because of the heat waves. [Their airplane] while making a turn, went into a tail spin and crashed [killing both men]."—*Assoc. Press.*

It is impossible to say what proportion of flying fatalities have resulted from vertical currents on hot days. Aviators are unanimous in saying that Texas has the bumpiest flying of any part of the United States.

The places where bumps occur are well known to aviators. Roads, railroads, edges of plowed fields, forest edges and clearings, barn roofs, hangars, ditches, borders of swamps, shore lines, all give bumps, the sources of which can be identified generally to 700 or 800 feet, and on calm days occasionally to 2,500 and even 3,500 or more feet. The bumps associated with macadam roads and other hot places are not necessarily directly over the road, but to leeward at a distance depending on the velocity of the wind and the height of the airplane. The effect of ditches seems to depend on the nature of the ditch. Some aviators at Rich Field allowed for fall of about 15 feet in crossing a sunken road in the vicinity of the field. An aviator said that over a certain ditch near the field where he was flying he always experienced a considerable bump; but he could not say whether or not there was a slight fall before the bump. Railroads have the same effects as roads. Creeks seem to have down currents over them. The following was told by Lieut. Morgan, one of the most experienced flyers at Carruthers Field:

His airplane which had landed on the bank of small stream on a very hot day had considerable difficulty in rising because the propeller did not seem to take hold of the light air. After the ship had risen perhaps to 500 feet it suddenly began to fall. The propeller, even though going at 1,400 revolutions per minute, seemed to do nothing, and the elevators did not respond until the ship was 50 feet from the ground. Then conditions became normal and the airplane began to rise slowly after having fallen to a height of only 10 feet.

An aviator trained at Rich Field said that he did most of his flying over the open woods just south of Waco; he chose the woods because he feared less from the bumpy condition of the air over the woods than from collisions with others over the smoother fields. Over these woods the bumpiness extends with a certain degree of roughness to 1,200 or 1,800 feet, and is perceptible to 2,500 feet. By common agreement, a green field is said to be the best landing place and a plowed field the worst (if forests and rough ground are excepted). In the air, cumulus clouds and the region immediately under the clouds are generally avoided because of their well-known rough character.

As to conditions along the coast, the following statement by Donald B. Kimball, a naval aviator, shows the effect of difference in convection over water and land surfaces:

On clear, hot days in summer a light breeze off the ocean will often spring up in the morning, the velocity of which increases toward afternoon. Such days make ideal flying for seaplanes if the pilot keeps his machine clear of islands or peninsulas. The air over the shore line of islands or protruding necks is especially treacherous on hot days, for violent bumps may catch the pilot unawares after navigating through the smooth air over the ocean [especially in such places where the water is rather cold relative to the beach, as at San Diego, Calif. The shore-line bumps on Chesapeake Bay, and the Gulf of Mexico may be scarcely noticeable in late summer.] As a rule, the depth of these bumps extends noticeably to about 1,500 feet, very rarely above 2,000 feet, the violence varying indirectly with altitude. These conditions are somewhat altered if cumulus clouds tend to form. The region just under and within the clouds is probably bumpiest of all and there appears to be a sharp decline in violence on climbing above the clouds. On a clear, hot day it is not an uncommon feat for a perfectly balanced machine to fly several minutes at altitudes under 1,000 feet without having the foot controls moved. On such a day I once even saw a pilot step from the front seat to the wing and thence to the rear seat at an altitude of about 75 feet. Such a feat would be almost suicidal in land flying on a hot day.

Otto Neumer, of the Signal Corps Meteorological Service, in discussing typical flight conditions over the head of Chesapeake Bay in winter, states that convectional currents or eddies have little effect upon the movement of the plane, even on passing under or through cumulus clouds. The crossing of the shore line is practically imperceptible.

Explanation of bumpiness.—The local vertical currents which occur on warm days are the result of the unequal heating of the lower air. The air next to the ground gets hot; and, therefore, expands. Over a bare, dry field the heating is greatest. Thus, the surface air locally may become considerably lighter than the cooler air at the same level or even above; and so at the first opportunity some of this heavier air moves laterally or comes down and forces some of the lighter air to rise. On a quiet day at the earth's surface the movement of this cooler air is marked by light, variable winds interspersed with calms. The process of displacement is intermittent. When there is a wind blowing, the occasions when the cooler air moves toward the warmer places are marked by gusts or slack wind. These gusts are the result not only of the combined strength of the horizontal components of convectional winds and of the general wind, but also of the quick, down movement of air, which has a higher velocity than the friction-limited wind next to the ground.

The reason for the bumpier conditions in the middle of the day and for the greater bumpiness in Texas than elsewhere is now apparent—the hotter the lower air relative to that above, the stronger are the convectional currents and the gustier the wind. The reason for the decrease in bumpiness aloft is that near the earth there are likely to be the steepest temperature and wind velocity gradients. Again, the upper limit of bumpiness is the upper limit of the convectional columns of detached masses of rising air; and in much of Texas, at least, the tops of the convectional upcurrents are marked almost daily by the tops of cumulus clouds. (Cf. figs. 6 and 7.) The locations of bumps over roads, railroads, plowed fields, open spots in woods, etc., depends on the differences in the swiftest of these to produce effects on an aeroplane more or less disconcerting to the pilot."

Down currents, marking the movement of relatively cool air over ponds (D), lakes, and clumps of trees (E, fig. 7), do not have the marked velocity of upward currents, but are more dangerous. Their boundaries may be sharp enough for an airplane to fly with one wing in and one wing out of the descending current, as over a reservoir in a wheat field in France.

Down currents may extend up to 6,000 feet over woods. Stunt fliers try to get into a rising column for a tail spin; and they say that a "hole" or "pocket" (i. e., a down current) is often fatal. Perhaps down currents were responsible for some of the 35 per cent of training fatalities ascribed to tail spins during the war. In diving, a very thrilling sensation is encountered if the ship enters a down current—the airplane seems to drop away from the pilot.

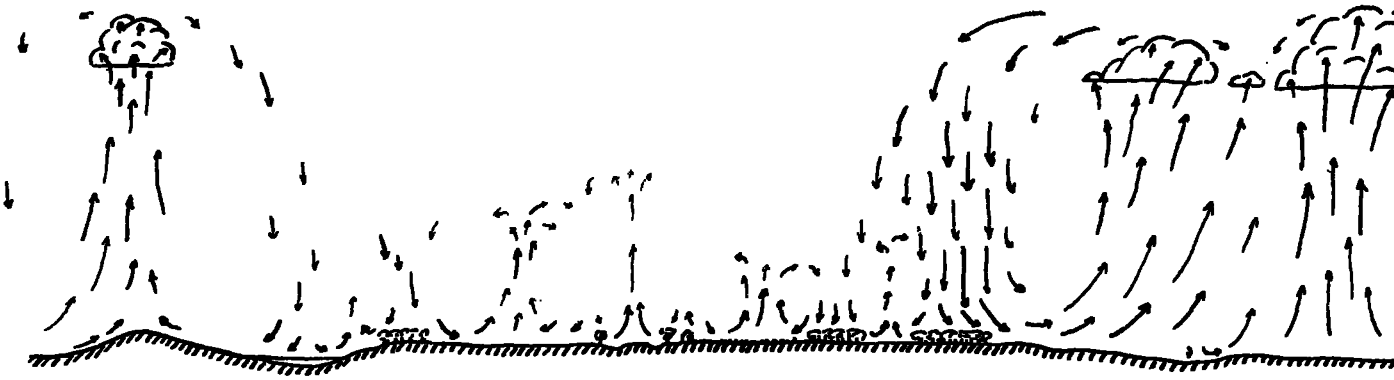

Fig. 7.—Local convectional currents on calm day.

degree of heating of different parts of the landscape. The road gets hotter than the fields on either side, and so the air from both sides flows toward, and displaces upward, the air over the road. (A, fig. 7.) Plowed fields are likewise hotter than the surrounding fields, because their dark, loose surfaces absorb so much more heat, and conduct downward so much less heat, than the surfaces of unplowed fields. Open woods favor bumpiness because some parts become hotter than others. (B, fig, 7.)

Isolated hills, especially short or conical ones, should be avoided during warm, still days, for on such occasions their sides are certain to be warmer than the adjacent atmosphere at the same level and hence to act like so many chimneys in producing updrafts. (C, fig. 7.)

The rising currents are interesting, not only because of the way in which they disturb aeroplanes, but also because they may be utilized by aviators who are trying to make altitude in the shortest time. Many use a rising air column that forms the cumulus, but they claim that many accidents have occurred because of the uncertainties of its direction and action. "Measurements on pilot balloons," says Prof. Humphreys, (2) "and also measurements taken in manned balloons, have shown vertical velocities [of convectional currents] both up and down, of more than 3 meters per second. The soaring of large birds is a further proof of an upward velocity of the same order of magnitude, while the fact that in cumulus clouds, water drops and hailstones are not only temporarily supported, but even carried to higher levels, shows that uprushes of at least 8 to 10 or 12 meters per second not only may, but actually do, occur." An aviator who has flown over an active forest fire never does so again, if possible. "There are, then, upward currents (some of which might be called 'air fountains') of considerable velocity whose sides at times and places may be almost as sharply separated from the surrounding atmosphere as the sides of a fountain of water, and it is altogether possible for the

Other air movements, which are perhaps equally distressing to aviators, are the mountain breezes down river valleys or other low portions of the country. These winds, sometimes of gale force locally, may be met very suddenly from almost calm air in approaching the mouth of a valley at times when the earth is cooling by radiation.

EFFECT OF TOPOGRAPHY ON WINDS.

The effects of heating and cooling of the earth's surface upon the flow of air is not the only cause of turbulence, for there is the effect of topography, which introduces phenomena quite as dangerous and distressing to the airman as convection.

Aviators' experiences.—Roughnesses (including trees and buildings) of the surface produce eddy motion, which in a moderate wind will reach to 1,000 or 2,000 feet and in a strong wind to 3,000 feet or more. Extremely rough conditions are experienced in a gale, as the following accounts show:

Subject: Report [to Post-Office Dep't] of flight from Philadelphia to New York, March 28, 1919.

Left Bustleton at 2:15 p. m. March 28, 1919, in plane No. 30, Curtiss R-4. Wind velocity, reported by Philadelphia Weather Bureau, 48 miles per hour; direction approximately 300° [WNW.]. Climbed to 3,000 feet before reaching Trenton. Steered compass course of 25°, allowing 40° drift angle. Severe bumps felt at all altitudes. Looking ahead snow could be seen. Directly to the rear, atmosphere clear. Passed over Trenton at 2:30. Having a short time before run into snow, which made it necessary to fly at 1,000 feet, at which altitude could just see the ground. Could not see enough of the ground to recognize any landmarks. Flew entirely by compass.

The next landmark picked up was the Woolworth Tower, New York City. Passed over it about 300 feet to the north; altitude about 900 feet. No very severe bumps felt directly over the city, but when passing over Brooklyn very severe bumps were encountered. These threw the plane about to such an extent that I was unable to watch my compass for several minutes. Extreme aileron and rudder were needed a number of times to bring the plane back to normal flight. Flew with motor wide open during this time (1,600 revolutions per minute).

While passing over Brooklyn the motor cut out three times. Turned on the gravity tank and it picked up again immediately. Then shut off the gravity tank each time it came back. Presumably this was caused by the severe bumps. One pocket over Brooklyn let the plane drop approximately 100 feet. It was so rapid that I was thrown full weight against the safety strap.

The snow became heavier, and in order to see the ground had to fly below 500 feet. The air continued very rough, and was only able to look at compass occasionally. At about 3:05 picked up a railroad and attempted to follow it, thinking that it might lead to Jamaica, but the country was not familiar and it was very difficult to follow the rails. Do not believe I was more than 200 feet. The air was very rough.

At 3:15 decided to pick a field and land. Attempted to do this, but on seeing a field would be driven past and it would be lost before I could turn and land. Then headed around into the wind and flying just over the buildings and trees, approached several fields, but they were all too small. At this point passed over a small body of water and felt the worst bump of the trip. Was not more than 80 feet and was thrown into a vertical position and back to normal almost before I could use the controls. What appeared to be a fair field was directly ahead. Throttled motor and zumed over a fence. On the farther side the ground rose in a gradual slope, and pulled back to land. Just as the wheels were about to touch, a current of air coming from the other side of the hill caught my plane and lifted it about 20 feet. Then the plane settled vertically to the ground, crushing the landing gear and breaking the propeller. This occurred at 3:20 p. m. on a field owned by John C. Baker, Great Neck, L. I.—*John M. Miller*.

At College Park, Md. [Mar. 28, 1919].—Pilot Bissle rose only 50 feet when his plane was forced downward as if some giant had placed his hand upon it and pressed it earthward. His landing gear was smashed.

Pilot DeHart, attempting to leave Belmont Park, New York City, for Philadelphia, could not get his plane off the ground on account of the downward "swirls" of the wind.—*Washington Post, March 29, 1919*.

During a gale the edge of the woods near Houston, Tex., is marked to a height of 1,000 or more feet. Bad bumps have been felt 2,500 feet above and to leeward of hangars on a windy day.

Neumer reports that on days with high winds in eastern Maryland "the air [up to 10,000 feet] seems to be moving in great horizontal eddies or rolls similar to the rolling of ocean waves. The airplane rocks just like a rowboat in the sea."

Such motion is sometimes sufficient to produce seasickness. A case occurred in southeast Texas in the spring of 1918: and another on a mail plane flying from Paris to London in the summer of 1918—"Owing to the straight head wind and deep air pockets, my observer and myself were really seasick, as though pitched and tossed on a heavy sea," said Lorgnat after landing. [1]

Many pilots have been questioned regarding the effect of topography upon the action of their planes at various altitudes. In addition to the natural configurations of the ground, there are also the effects introduced by buildings, groves of trees, and other obstacles over which the wind must pass. The general opinion is that these effects do not extend upward nearly so far as strong convection does, except, perhaps, in very rough, mountainous country or with winds of gale force. It appears also that the altitude to which such disturbances may extend is proportional in general to the wind velocity and the size of the surface irregularities. A combination of a strong north wind and bright sunshine on June 13, 1918, caused bumpiness which was extreme even as high as 6,500 feet, the maximum altitude reached by J. C. Edgerton on his mail plane flight from Washington to Philadelphia on that day.

[1] Note in Scientific American, Aug. 24, 1918, p. 147.

Here are some aviators' accounts:

Almost invariably offshore winds are accompanied by bumps and eddies which cause fatiguing flying. A 10-knot shore breeze makes more trouble than a 20- or possibly 25-knot sea breeze. Evidently this is due to the uneven contour profile of hills, trees, and houses on the land as compared with the sea.

Air bumps from offshore breezes appear to be of a different nature from those occurring over islands in a sea breeze. Under the former conditions the bumps come in gusts and in fairly steady succession. An inexperienced pilot may attempt to keep his machine on an even keel by adjusting the controls for each bump separately, but he soon learns that control, especially with his "ailerons," is practically unnecessary. Alertness in the use of "elevators" is always advised by the instructor. The golden rule of flying is, "Retain flying speed;" therefore the bump which raises the nose of the machine and diminishes the speed must be balanced by a corresponding lowering of the elevators to regain that speed.

Bumps from gusty offshore breezes extend to varying heights. I have encountered them as high as 5,000 feet. They are not always strongest at the lower altitudes. I have seen days when the riding was rougher at 1,500 feet than at 500 feet. It is rather treacherous "to be off" close to a protected shore in an any degree brisk shore breeze for there is a sharp outline at the level of the height of protection. For instance, in taking off toward a hangar, it is not uncommon to pass suddenly from a relatively smooth region to a very bumpy one in swooping up over the edge of the hangar.—*Donald B. Kimball*.

When passing over buildings, groves of trees, or similar obstacles, bumps are generally experienced, their extent being influenced mainly by the strength of the wind. As obstacles of this character are approached with a following wind the machine will lift and drop with equal suddenness on the other side. If approached head to wind the converse will take place—the machine will probably drop, sometimes nearly to the ground, just before reaching the obstacle, and rise as it leaves it. This seems to be due to the fact that when the wind strikes the obstacle it shoots upward. [Fig. 8.] It would be difficult to say what height this updraft generally reaches, but the writer's experience is that it goes up well above the actual height of the obstacle, and is "flattened out" on the other side, where there is often an unmistakable down current.—*Lieut. S. W. Addison*. (1)

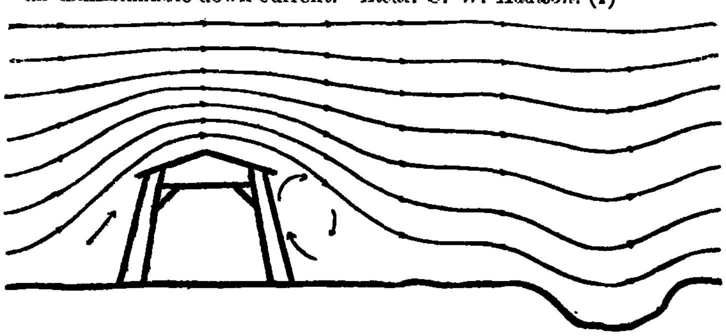

FIG. 8.—Effect of minor surface irregularities on lines of wind flow in a light wind. (From Linke. (10))

The deflected vertical currents consequent upon a surface breeze meeting a belt of trees have often lifted the writer's machine, just in the same manner as a long ground roller does a small boat. This is easy to anticipate when a breeze is noticeable on the ground, but is at first apt to come as a surprise, when on the ground practically no air movement can be detected.—*Capt. H. H. Storrer*. (1)

A wind makes flying much harder for the airman, not because of the actual wind itself, but on account of its constantly changing velocity and direction. The change of direction of a wind is its worst feature, and causes the machine to "yaw" badly, and so makes it difficult to keep the machine on its course. The wind also changes in direction vertically, and, when we experience this change, the equilibrium of the machine is upset. When flying at a low altitude I have noticed that any irregularity on the surface will cause a change of direction upward or downward and cause the machine to rock, sometimes very badly. If the objects on the ground are of a prominent nature, such as the many belts of trees on the aerodrome, I have experienced a condition which causes the machine to "flop" about in all directions, and is most distracting. I attribute the cause of this to a horizontal eddy being formed near these objects.—*D. P. Flockart*. (1)

The turbulence caused by hills or mountains depends largely on the local topography and on the winds concerned. Point Loma, near San Diego, Calif., gives birth to marked turbulent conditions over and to leeward of it.

Dr. F. A. Carpenter describes the conditions as follows (he was in an airplane at 2,000 feet altitude headed seaward toward Point Loma): [1]

Suddenly there were two distinct "wallops" and I felt the fuselage beneath me respond as if struck by a stuffed club. There was evidently first a surge then a drop, and it was the descending current of air that deprived the airplane of the supporting medium, hence the shock. * * * Although this peninsula (Point Loma) is less than 500 feet high, it so effectively deflects the prevailing northwesterly wind that the upward surge has been noticed by aviators at an altitude of 4,000 feet. It is no wonder, then, that these descending winds, called "woollies" (from their churning up the water into isolated masses which look like tufts of wool), are dreaded alike by yachtsmen and birdmen. They have been known to carry away topsails from too closely venturing schooners, and student aviators always give the vicinity of Point Loma a wide berth.

An aviator flying at 3,500 to 4,000 feet inland from San Diego with the wind, passed over some mountains 2,000 feet high. On the lee side he was forced down, or fell, 1,500 feet. The prevailing cloud sheet at 4,000 feet gave from below no notable indication of such a current, but it seems probable that the upper surface would have showed where the wind was up and where down. The upper surface of this "velo" (stratus) cloud sheet is usually uneven; but this aviator on other occasions had not happened to find how to tell from the form of the cloud surface the underlying topography.

The following, from log of balloon flight made by Lieut. W. F. Reed, jr., on flight from Akron, Ohio, to Fredericksburg, Va., September 16–17, 1919, shows how the wind tends to hug the surface in going over a ridge:

6:20 a. m., 2,400 feet.—Passed over sharp ridge. The balloon was allowed to approach the ridge without discharging ballast; it looked as though we would bump the cliffs, but the upward current carried us over the top. The trees on the crest looked at first like mere weeds, but a closer view showed them up as full-grown trees and we could hear the wind rustling through the leaves. We went down with the current on the leeward side at an altitude of 200 feet above ground until we were halfway down.

Going against the wind up over a mountain region the aviator may have difficulty in keeping his altitude. Lieut. Vance reported:

I had one unusual experience with bumpy wind. It was in October, 1918, when I was leading a formation northwest in the face of a north wind, from Birmingham, Ala., to Fayette, Ala., over very hilly country (hills about 1,000 feet covered with forests). I attained an altitude of about 1,500 feet before striking NW. and travelled for more than an hour trying to climb, and actually settling all the time. It was during the forest fires in Minnesota, and all the air was smoky, very dense. All the other flyers of the squadron had the same experience.

At the time when the smoke was over the South, an extensive anticyclone covered the eastern United States—possibly the settling experienced was due to the general downward movement of the air in the anticyclone rather than due to topographic influences.

The air over a mountain region is usually turbulent. Capt. F. N. Bartlett, in a flight from Scott Field, Ill., to Kelly Field, Tex., a year ago had nine hours of difficult flying over the Ozarks between Eberts Field, Ark., and Post Field, Okla. This turbulence attendant upon flying over the Ozarks was strongly manifest in a recent balloon trip from Fort Omaha, in which it was desired to maintain a constant elevation of 5,000 feet above sea level. This was found absolutely impossible and the balloon often was dragged down to within a short distance of the ground, or caused to ascend again, almost out of the control of the pilot.[2] The accompanying balloon at 10,000 feet was but little affected. On windy days over rough topography, bumpiness has been generally observed to 4,000 feet.

Lieut. R. O. Searles, the flight commander of the De Haviland squadron, which made the trip from Ellington field to the Pacific coast and back, related that on the 24th and 26th of February, 1919, it was not possible to enter the Grand Canyon with a plane, but that it was easily possible on the 25th. Sergt. E. B. Scott indicates this was doubtless due to the pressure distribution on those dates, for on the 25th the gradient wind was not of great speed and, moreover, conformed with the direction of the canyon, whereas on the preceding and following days the pressure gradient was steeper and the wind direction was such as to produce great turbulence in passing across the canyon. It has been reported that in a strong south wind the back-and-up current of the eddy in the lee of the south wall of the Canyon has carried tin cans up the cliff and into the yard of the hotel. A canyon near Kelly Field, Tex., has the reputation of being a dangerously rough place. The winds are this way and that; now up 100 feet, then down 100 feet. One loses practically all control of the airplane.

Interpretations.—*Wind eddies.*—"Just as eddies and whirls exist in every stream of water, from tiny rills to the great rivers and even the ocean currents, wherever the banks are such as greatly to change the direction of flow, and wherever there is a pocket of considerable depth and extent on either side, and as similar eddies but with horizontal instead of vertical axes occur at the bottom of streams where they flow over ledges that produce abrupt changes in the levels of their beds, so too, and for the same general reasons, horizontal eddies occur in the atmosphere with rotation proportional, roughly to the strength of the wind. These are most pronounced on the lee sides of cuts, cliffs, and steep mountains; but also occur, to a less extent, on the windward sides of and above large obstructions." (2)

FIG. 9.—Wind crossing a ridge. (From cloud movements observed along the Hudson River, Aug. 4, 1918.)

"The inertia of the wind crossing the mountains tends to carry it on well above the valley or plain beyond, but its drag on the lower air, due to viscosity, deflects it downward. [Fig. 9.] Because of this deflection a foehn wind often strikes the lower slopes with great violence, from which, and mainly because of its dynamical heating, it rebounds to higher levels. Along a belt, therefore, well down the mountain, or even slightly beyond its base, the surface wind may be exceedingly turbulent and violent, while both farther away and also on the higher slopes it is comparatively light. Furthermore, owing to changes in the general direction of the crossing current, or in its strength, or both, the wind belt may shift up or down the mountain or even vanish entirely."—*W. J. Humphreys.*

"The air at the top and bottom of wind whirls is moving in diametrically opposite directions—at the top with the parent or prevailing wind, at the bottom against it—and since they are close to the earth they may, therefore, be a source of decided danger to aviators. There may be some danger also at the forward side of the eddy where the downward motion is greatest.

"When the wind is blowing strongly landings should not be made, if at all avoidable, on the lee side of and close to steep mountains, hills, bluffs, or even large buildings, for these are the favorable haunts, as just explained, of treacherous vortices. The whirl is best avoided by

[1] The Aviator and the Weather Bureau, San Diego, 1917, pp. 19–20.
[2] See page 535, reference to Lieut. Reynold's account, balloon article.

landing in an open place some distance from bluffs and large obstructions, or, if the obstruction is a hill, on top of the hill itself. If, however, a landing to one side is necessary, and the aviator has a choice of sides, other things equal, he should take the *windward* and not the *lee* side. Finally, if a landing close to the lee side is compulsory, he should if possible head up the hill with *sufficient velocity* to offset any probable loss of support due to an eddy current in the same direction. He could, of course, avoid loss of velocity with reference to the air, and therefore loss of support, by heading along the hill, that is, along the axis of the vortex, but this gain would be at the expense of the dangers incident to landing in a side or cross wind. His only other alternative, heading down the hill, might be correct so far as the direction of the surface wind is concerned, but it probably would entail a long run on the ground and its consequent dangers.

"Eddies of a very different type, relatively small and so turbulent as to have no well-defined axis of rotation, are formed, as is well known, by the flow of strong winds past the side or corner of a building, steep cliff, and the like. In reality such disturbances are, perhaps, more of the 'breaker' type, presently to be explained, than like a smoothly flowing vortex, and should be avoided whenever the wind is above a light breeze.

"Clearly, the support to an aeroplane flying either with or against a wind of this kind is correspondingly erratic, and may vary between such wide limits that the aviator will find himself in a veritable nest of 'holes' out of which it is difficult to rise, at least with a slow machine, and sometimes dangerous to try. However, as the turmoil due to the horizontal winds rapidly decreases with increase in elevation, and as the aviator's safety depends upon steady conditions, or upon the velocity of his machine with reference to the atmosphere and not with reference to the ground, it is obvious that the windier it is, the higher, in general, the minimum level at which he should fly." (**2**). Cf. Mr. Miller's account, pp. 525–526.

Effect of gusts.—Aside from the obvious effects of vertical currents, already discussed, the mere changes of velocity in a horizontal direction that accompany the passage of gusts tend to produce an up-and-down motion in an airplane flying with or against the wind. If the airplane is flying with the wind, any increase in the velocity of the wind will momentarily reduce the support of the airplane, thereby causing it to drop, while any decrease in velocity will momentarily increase the air speed of the machine, tending to make it rise. The reverse is the case if the machine is going against the wind.

This is because in a steady wind an airplane itself moves as if in a calm. Thus if the wind is unsteady the number of gusts encountered in a given time will be the same whether there is a following or a head wind. And if, as the anemometers indicate, gusts have no more abrupt onset than end, the effect of a gust from in front or of a lull from behind should be the same. Nevertheless, aviators say they can feel the difference between a head wind and a following one, and that they climb fastest against the wind. Soaring birds have the same experience. This would seem difficult to explain in any other way than that gusts begin more suddenly than they end. Apparently, we need more refined observation to show what the difference is.—*Abstract from C. C. Turner, Aeron. Journ., (London)* **22**: *285–6, 1918.*

Effect of gustiness on a turning airplane.—Probably the chief disturbance due to gusty wind—excessive tipping and side slipping—occurs not during straightaway flying but as the aviator turns at low levels from flying against the gusts to flying with them. For example, on April 3, 1919, Lieut. Col. F. T. Dickman and Maj. J. W. Butts, were killed in such a disturbance near Americus, Ga.

The two officers * * * had made the last turn of the field preparatory to landing. From the ground it appeared that Maj. Butts attempted to turn. The wind was coming in gusts and apparently caught the airplane with full force in such a way as to lift the tail vertically into the air. The usual nose dive followed the jerking of the plane into a vertical position, and it crashed to the earth.—*Washington Post, April 4, 1919.*

"Such an accident may be, and presumably is, caused as follows: The aviator starts turning, suppose, while in and facing a relatively slow-moving portion of the air. On banking, the plane is tipped with its underside more or less against the wind, whereupon the higher wing often runs into, or for brief intervals is caught by a much swifter current than that into which the lower still dips. Numerical values are not at hand, but the phenomenon of overrunning gusts is familar from the action of winds on isolated tall trees. This obviously increases the tip, and, in extreme cases, sufficiently to induce a dangerous side-slip.

"On the other hand, when turning from flying with to flying against the wind the high wing catches the increased impact on its upper side, and therefore in this case the result is merely a temporary decrease of the tip—an entirely harmless effect. Gusts that envelop the whole of an airplane while turning obviously affect the lift to some extent, even when the path of the wind is at right angles to the course of the plane, but seldom sufficiently to be of much importance." (**2**)

WINDS OF THE FREE AIR: TURBULENT WIND BOUNDARIES.

The difficulties of the pilot do not cease once he has risen above the turbulence of the lower air produced either by local convectional currents or by the tumbling of the wind over the surface of the earth. For example:

Mr. J. C. Edgerton, flying the mail plane between Washington and Philadelphia, July 4, 1918, rose above the surface bumpiness into much cooler air at 5,000 or 6,000 feet and had smooth flying until from 9,100 to 11,300 feet he experienced up and down currents, some of them strong. The logs of his mail flights are full of similar instances of bumpy layers at various elevations. On June 1, 1918, the air was bumpy between 2,500 and 4,000 feet and again from 5,500 to 6,500 feet between Washington and Baltimore, and between 7,000 and 8,000 feet near Philadelphia. On descending, the air was especially bumpy at 200 feet. Returning in the afternoon, heavy clouds had formed to a height of 10,000 feet, and vertical movements extended up to this height. In the vicinity of rain squalls the air was extremely bumpy and "sharp cross currents threw me off my course repeatedly." On descending, it was increasingly bumpy down to 2,000 feet. Aloft, a cold west wind overrunning a southwest surface wind, was evidently responsible for the convectional currents which made the clouds and rain and the bumpy condition of the air, first in two zones of moderate thickness and later throughout the lower 10,000 feet of the atmosphere, at least.

Rohlfs on his recent record-breaking altitude flight to 34,610 feet, September 18, 1919, said that even "at 31,000 feet, my machine hit a pocket and dropped 600 feet. It rocked from side to side, a terrible sensation.—*From newspaper account, September 19, 1919.*

Referring again to the flight of Capt. Bartlett, we find this newspaper statement:

Waiting here [Waco, Tex.] for the storm to pass, he took off again under black clouds which hung as low as 600 feet and with a strong south wind along the ground. He climbed to 3,000 feet and there found clear air and a brisk north wind.

There are numerous accounts by aviators which tell of wind boundaries which are entirely invisible. Says one:

Near the surface the air was comparatively calm, but when about 800 feet was reached the machine was noticed to pitch slightly, just as a vessel might do in a sea with a slight swell. These conditions continued until about 1,000 feet. On another occasion, when the ground temperature was 34°F., following a severe frost, somewhat similar conditions prevailed. Near the surface absolute calm prevailed until nearly noon; but at 800 to 1,000 feet a long, uniform "swell" was encountered, the "waves" being probably 50 feet in depth, over which the machine rode gracef lly and smoothly. *Lieut. S. W. Addison.* (1)

"Ordinarily there is not more than 100 feet of turbulence on wind boundaries. The boundary separating two winds is easily noted by the great disturbance, and bumpiness, the violence of which depends on the velocity of the winds. In many instances the change of winds will be just above where the cloud layer is forming or slightly above the haze."—*E. M. Powers.*

"*Wind layers.*—For one reason or another it often happens that adjacent layers of air differ abruptly from each other in temperature, humidity, and density, and therefore, as explained by Helmholtz, may and often do glide over each other in much the same manner that air flows over water, and with the same general wave-producing effect. These air waves are seen only when the humidity at the interface is such that the slight difference in temperature between the crests and the troughs is sufficient to keep the one cloud capped and the other free from condensation. In short, the humidity condition must be just right. Clearly, then, though such clouds often occur in beautiful parallel rows, adjacent wind strata of different velocities and their consequent air billows must be of far more frequent occurrence.

"This fact is abundantly proved by all types of aerological work, as well as by all those who ascend into the air. Kite balloons in ascending are often seen to rotate, pointing their noses in various directions, indicative of various wind directions at different levels, yet there may be no cloud layer at the interface to mark it. Free balloonists make use of these layers of air, which may have different directions and speeds, in order to aid them in achieving whatever result they seek, such as distance or a given destination." (2)

"*Wind billows.*—When one layer of air runs over another of different density billows are set up between them, as is often shown by windrow clouds. However, the warning clouds are comparatively seldom present, and therefore even the cautious aviator may, with no evidence of danger before him, take the very level of the air billows themselves, and before getting safely above or below them encounter one or more sudden changes in wind direction and velocity due, in part, to the eddy-like or rolling motion within the waves, with chances in each case of being deprived of a portion of the requisite sustaining force. There may be perfect safety in either layer, but, unless headed just right, there necessarily is some risk in going from one to the other. Hence, flying at the billow level, since it would necessitate frequent transitions of this nature, should be avoided.

"When the billows are within 300 meters [1000 ft.], say, of the earth (often the case during winter owing to the prevalence then of cold surface air with warmer air above) they are apt to be very turbulent, just as, and for much the same reason that, waves in shallow water are turbulent. For this reason, presumably, winter flying sometimes is surprisingly rough. Fortunately, however, it is easy to determine by the aid of a suitable station barograph whether or not billows are prevalent in the low atmosphere since they produce frequent (5 to 12 per hour roughly) pressure changes, usually of 0.1 mm. to 0.3 mm. at the surface." (2).

CLOUDS AND RAIN.

Flying in clouds or above them is the choice of the aviator over enemy territory more than over friendly country. How the aviator in the United States feels toward the clouds is well shown by the classification of the weather conditions under which the postal aviators between Washington and New York have to fly (Aerial Age Weekly, July 8, 1918, pp. 816–817). In succession these are—ideal, fair, occasional clouds, frequent clouds, high winds, thick clouds, thick clouds and high winds, rain storms, combination of storms and heavy fogs. Clouds are generally avoided because one can not see where he is going nor keep right side up. Cumulus clouds, particularly those with hard-looking outlines, are avoided because of their bumpiness, coldness, and fogginess; also, not infrequently because they have falling rain. (Fig. 3.) Such clouds are usually roughest and wettest at their bases. An aviator at Wichita Falls, Tex., on approaching a large cumulus cloud rose to fly over it; but it "towered to the sky," so he flew through. Once inside, he said the cloud was so dense that he could not see the tail of the airplane, and that it required all his flying ability to keep his direction. A full account of "Danger in flying through clouds," by Capt. B. C. Huchs, was presented to the Aeronautical Society of Great Britain, and reprinted in Scientific American Supplement, June 15, 1918, page 375.

Strato-cumulus clouds and cumulus clouds with fuzzy edges have weaker ascensional currents and are less bumpy to fly through. (Figs. 4 and 5.) Aviators in flying about such cumulus clouds can easily lop off corners and even make small clouds evaporate by flying through them. Some cumuli have cavities 1,000 feet high in their bases. On one of the hottest Texas days, an aviator had some trouble with an overheated engine, so he flew in the disconnected patches of strato-cumulus clouds at 10,000 feet. These clouds were cool and smooth. They marked, nevertheless, the tops of convectional currents, which were prevented from going higher, apparently because of an inversion of temperature at that level. On descending, the avaitor had considerable difficulty with bumps in the lowest 500 feet. Strato-cumulus clouds which grow out of stratus on summer mornings are not particularly bumpy. At least, aviators in speaking of flights up or down through them have mentioned only the beauty of the tops or the vertical thickness of the cloud. Fogs and stratus clouds are real blinders for the aviators although the use of radio-directional apparatus is reducing the danger of getting lost.[1] In the Houston region, the stratus are often so low that flying below them is not attempted for fear of tress. An aviator above low stratus clouds, or over a fog is in a very difficult situation if he needs to land.

An occurrence at Love Field early in September, 1918, makes a good example. While 60 aviators were in the air, low-lying clouds suddenly appeared and gave a drizzling rain at 10 a. m. Before it cleared away, 21 of them had to come down in wet fields, and two airplanes were demolished because the pilots could not see to select their landing places. One lit in a pond and the other in a tree.

Flying in the rain is avoided, if possible. Even in midsummer in Texas, at 7,000 feet in the air, an aviator flying through a rain cloud felt so cold that he described the rain drops as "ice particles." The impact of rain drops is sufficient to make them feel solid. On this occasion, there was a considerable collection of water on the airplane. The weight of rain water can hardly affect the performance of the airplane much, unless the drops freeze on. In the spring of 1918 an aviator in Texas had such an experience during a shower; he flew up into a

[1] Cf. Wireless navigation for aircraft, *Nature* (London), Sept. 11, 1919, pp. 24-27.

cloud until at 7,000 feet his airplane had become so covered with ice that he could go no higher. The effect of rain on the propellor is destructive. The propeller moves at such a high velocity that unless specially protected the rain drops cut it as if they were bullets.

Airmen are unanimous in regard to the danger and unpleasantness of flying through rain and fog. To quote from the Scientific American, July 13, 1918, page 26, on "The Fog Problem in Aviation":

It is hardly an exaggeration to say that at the present time the only serious outstanding meteorological problem of the aviator is fog.

There is no means [except radio] of keeping one's bearings when flying in or over a fog, and the same is, of course, true of low-lying clouds. The compass tells which way the machine is pointing at any moment, but not the direction in which it is flying, except when traveling exactly with or against the wind. There are no landmarks in the air. Even more serious is the problem of landing in a fog. The chances are always considerable of striking dangerous obstacles, such as trees, buildings, or telegraph wires, or of alighting in bodies of water, swamps, etc.

Moreover, as one veteran flyer has stated: "What is distressing to the airman in fog is the impossibility of knowing whether he be slightly climbing or slightly descending, with the result that he may find himself charging full-tilt into hills, trees, or houses without time to save the situation."

In the recent air race from New York to San Francisco, Lieut. Edward V. Wales was killed by driving his plane into Elk Mountain, Wyo., during a blinding snow storm.

Aside from the general unpleasantness of flying in rain, the water may cause faulty engine action by getting into the carburetor and the ignition system. As to general turbulence within clouds, there is very little definite information from aviators because the propeller so violently churns up the air in the neighborhood, and this mixing is often sufficient to mask any real small-scale turbulence that may exist there.

THUNDERSTORMS.

In thunderstorms, however, these turbulent conditions are of considerably greater magnitude, and are, in fact, so violent that great danger is entailed in flying in or about them. Indeed, few aviators have flown into a thunderstorm and come out alive.

Experiences.—Lightning is one danger. About August 1, 1918, an aviator flew into a thunderstorm at Paxton, Ill., and was found dead, with lightning burns on his body. Another aviator a year earlier, thinking apparently that the thunderstorm was going with the lower wind flew into the storm and was killed. Several years ago a flyer named Ehrmann had his machine set on fire by lightning, but he escaped unhurt.—C. C. Turner, "The Romance of Aeronautics," page 229, *Philadelphia, 1912*.

Capt. Cave (**12**) says:

It is possible that the actual danger from lightning to an aeroplane flying through a thunderstorm may be no more than that incurred by a pedestrian walking across an open common during a storm. A pilot who was flying above a thunderstorm last summer reported that long sparks were given off by this machine at intervals. It is very likely that this happened every time there was a flash of lightning from the cloud below him.

Aviators in the United States have also experienced such discharges while flying in thunderstorms or through gaps between thunderheads.

The *turbulence* within a thunderstorm is awful to experience.

A French machine was called upon to ascend during a violent thunder and windstorm for important observation work over the German lines. When at a height of several thousand feet the members of the squadron below saw the turret and its machine gun stripped from the craft by the gale.

The observer's seat was next to go, but the occupant, grasping the wing stays, clung to the sailing plane. The craft was whipped about in the sky at will and the cloth completely stripped from the fuselage. Both pilot and observer were clinging to their broken craft when it reached earth after a series of gyrations rivaling the most daring acrobatics practiced by the Allied aces. Both occupants escaped serious injury.[1]

It is quite likely that in such cases pilots and observers think very little of thunderstorm structure or the meteorological aspects of the situation. An aviator told this story of a friend's experience:

Lieut. Dunn got into a thunderstorm once. There was lightning all around him; but it was pitch black otherwise. He jerked all the controls and the ship apparently did not respond. He went up and down and was helpless. He was certain he would be killed. One minute he would think he was O. K. and the next minute he thought he was on his back.

Another aviator, Lieut. Vance, says:

I was once caught in an approaching thunderstorm. I noticed that I was gaining altitude very rapidly, so nosed the plane down, but could not lose any altitude until I had gained up to 4,000 feet. I was in the clouds most of the time. I just kept the nose down, and finally came down; then I commenced to settle, and could gain no altitude even at the maximum climb.

Again:

Capt. Bartlett was caught in a severe storm over Arkadelphia, Ark., and held in that situation for 35 minutes. "His plane settled from an altitude of 6,000 feet to 3,000 feet and drifted about two miles sideways, when he finally broke through the storm and came out miles off his course but in dry weather."[2]

Lieut. F. Davis is reported to have fallen to within 300 feet of the ground in trying to fly through a thunderstorm near Memphis, Tenn.

"An Australian aviator, Lieut. H. W. Ellis, reports that he ran into an isolated storm cloud and received two downward bumps, caused by descending currents. These bumps were very severe, and the speed gauge registered well over 90 miles per hour." (**1**) Also he states that "on one occasion (about September, 1915), a machine got into a black or thunder cloud, and was turned completely round, at the same time receiving a downward bump."

As an example of the dangers encountered in the vicinity of thunderstorms, the following is quoted from the account of Lieut. G. S. Mason, U. S. N.:

On July 23, 1919, near Pensacola, Fla., machine No. 2474 was in horizontal flight approaching a squall on the right. As we passed a small black-fringed cloud, at about 1,500 feet altitude, I felt bumps affecting the plane emanating from the cloud. I started to glide lower, thinking to avoid these apparently local bumps, when the plane suddenly nose dived, so suddenly, in fact, that the gasoline was thrown out of the venthole in the carburetor, flooding everything and stalling the motor. I was thrown up under the yoke of the controls and for some little time was unable to recover my seat, although I pushed up hard to force myself down. The machine was then in vertical nose dive, with no pressure on the flippers. I kept the flippers neutral, realizing that when I obtained pressure on them it would be sudden and very possibly collapse the wings. Trying the flippers occasionally, I finally got them to take hold after losing between six and eight hundred feet altitude.

An aviator related that one evening in the vicinity of San Antonio, Tex., local thunderstorms forced a landing, and that later the flying was the bumpiest he ever experienced. He said there was a thunderstorm every 3 or 4 miles. Lieut. Weddington reported:

I experienced rough riding between Wichita Falls and Gainesville, Tex. My ship was tossed up and down like a leaf, falling as low as 500 feet and rising suddenly to 2,500 or 3,000 feet.

Lieut. E. M. Powers wrote:

I have found that flying just in front of a thunderstorm is the most trying experience an aviator can have. The bumps are very violent and rapid, though they are usually not very deep, 200 feet being the greatest. Sometimes the ship will fall with such rapidity that the water will spurt from the vent in the radiator cap and I have even had the gasoline spurt out. However, it has been my experience that when the heavy rain is encountered the bumpiness decreases. On one occa-

[1] W. S. Forrest, New York Tribune report, July 14, 1918.
[2] From newspaper account October, 1918.

sion, June, 1918, I flew just in front of a good-sized storm. It was the only cloud, with the exception of a few white ones that were small, in the sky. The wind started to blow and the clouds were rolling one over the other when I started across the face of the storm. My altimeter said 2,800 feet and the clouds were approximately 1,000 feet above me. It finally got so rough that I came down to 1,500 feet and found that the air was lots more smooth. Later I passed just to the rear of the storm, through some of the rain, and found that the air was perfecty quiet and remained so until I passed from over the dampened area, when I ran into the usual hot-day bumpiness.

Many aviators have experienced the great up-current which occurs on the front of the squall wind issuing from the base of a thunderstorm. Ascents of several thousand feet have been reported not only in Texas but also in Florida. Two of the most striking ones, both from Texas, will be cited. On one occasion, near Fort Worth, the aviators began to return to Carruthers Field on the approach of a thunderstorm. Lieut. Morgan on banking for a turn while just over the squall front was suddenly lifted from 2,000 to an elevation of 7,000 feet, a rise of 5,000 feet in almost no time. He thought that his altimeter had "gone crazy." On descending immediately he reached the field just before the squall struck it. Other aviators were lifted similarly by 2,000 to 4,000 feet. Those that landed after the "50-mile" squall began had to land with their propellers going full speed.

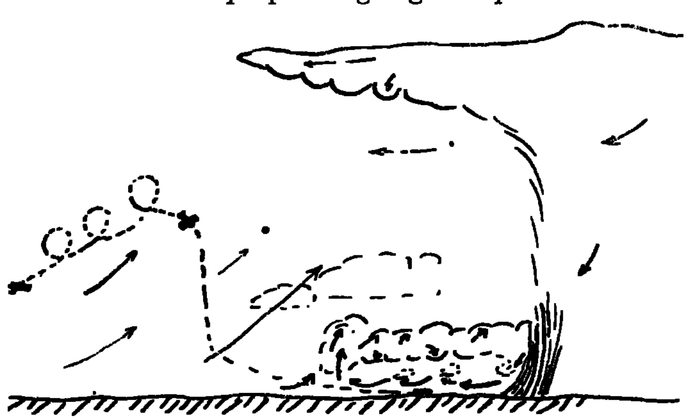

FIG. 10.—Winds experienced on thunderstorm front near Love Field, Tex., from description by Lieut. Cobb.

In the other instance, Lieut. Cobb was "stunting" near Love Field at about 3,500 feet altitude during the approach of a thunderstorm. After doing three evolutions, taking about 15 minutes, he found that he had gained some 3,500 feet in altitude, instead of losing 1,500 feet, as was usual. Sometimes the lifting would be of the order of 500 feet in a minute. This indicates that there was a wind with an average vertical component upward at about 5 miles per hour (2 m/s) blowing toward the storm, an upward rate quite to be expected under such circumstances. At the end, the aviators noticed sharp mammato-cumulus above and strato-cumulus clouds below them. They seemed to be at an altitude about midway between them, though they were some 5 miles away from the storm front. On descending they soon entered extremely bumpy air and were able to land only by diving into the wind with the engine on (Fig. 10). The rain began immediately after that. Landing in thunder squalls presents considerable difficulty. Once an aviator above such a squall, in the opposite return current, headed into the wind and made a descent to the field. He did not observe that the surface wind was opposite in direction. As he approached the landing place he noticed that for some reason he was not losing speed, and when only 5 feet from the ground saw that he was going with the wind. He was moving so fast that he went 4 miles before getting sufficient elevation to turn and come back. Others have had similar experiences, though careful observation of dust, smoke, windmills or trees would show the surface wind direction. The main difficulty of landing in a squall wind seems to be due to its variable sustaining qualities, which nearly always make a smooth landing impossible. Very frequently, also, just as a landing is being made, or later, a gust will overturn the ship, even if the propeller is run at full speed.

Interpretations.—The air movements about thunderstorms, in the lower level at least, seem to be relatively simple. The heavy fall of rain and the coolness of the air under a thunderstorm produce a down-flow of air which spreads laterally in the form of a squall. The squall wind is stronger than the forward rate of advance, and so there is a considerable rate of ascent on the front; and the cold squall wedge also forces up the warm general wind. The air which goes down from a thunderstorm is supplied by a return flow of low velocity above the squall. (Fig. 10.) This return takes place above 1,000 or 2,000 feet and is probably strongest at 3,000 feet or higher. In the front of the squall the presence of obstructions will locally increase the rate of ascent of the air, especially when such obstructions are in the lee of a flat area. The extraordinary up-current near Fort Worth, referred to above, occurred just in the lee of Lake Worth. An airplane in the rain under the thunderstorm is likely to be carried down not only by the weight of the rain but also by the downflow of the air. An airplane in the squall itself is likely to be disturbed by eddies. An aviator who wants to go around a thunderstorm will find the fastest going at a height of about 2,000 feet, between the outflowing wind below and the inflowing one above.

AIR DENSITY CHANGES AS AFFECTING SUPPORT.

On cold days with high atmospheric pressure an airplane has little difficulty in "taking off." For example, Capt. H. H. Storrer (1) cites an instance when with the barometer at 30.67 inches and the temperature 30° F. "one could ascend at a fair rate with the elevators in the position usually employed in horizontal flights; this, of course, in calm air."

On hot days or at altitudes of a few thousand feet, on the contrary, the rarefied air often makes it difficult to rise from the ground. Aviators at Kelly Field, Tex., and Fort Sill, Okla., have noticed repeatedly that on very hot days there was difficulty in taking off, due to the rarefied air. More striking than this, however, is the case of failure of the propeller to "take hold" in the rare air of higher elevations. Lieut. Nutt, of Ellington Field, Tex., accustomed to the distance required to take off in low elevations, failed to take into account the fact that a greater distance would be required at a higher elevation, and at Denver, Colo., October, 1918, crashed into a fence in consequence.

Not only are these difficulties noticed in taking off, but also are they troublesome in landing, for the plane continues to roll along the ground for an unusual distance before coming to a stop. Landing fields at relatively high elevations should be larger than those near sea level and also at their edges should be free from obstructions like telephone and power lines, which might be permitted at lower levels.

ACKNOWLEDGMENTS.

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CONCLUSION.

From the accounts of the numerous exciting experiences aviators have because of the conditions of the air, it is obvious that the more meteorology an aviator knows the better he can handle himself in the air, other things being equal. Furthermore, it is evident that the airplane has opened to the professional meteorologist a new and potent means of investigating the phenomena of the air. Much can be surmised from careful observations of cloud movements taken from the ground; but how much more satisfactory it is to be able to fly up and investigate, personally, what is happening!

The Weather Bureau would be glad to receive accounts of unusual flying experiences ascribable to weather or air conditions.

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FIG. 3.—Tops of large cumulus clouds.

FIG. 4.—Sunrise from airplane. (Notice two planes.) (Strato-cumulus.)

FIG. 5.—Thin layer of strato-cumulus.

FIG. 6.—Height about 5,000 feet. (Strato-cumulus.)